OAHU ARMY NATURAL RESOURCES PROGRAM
MONITORING PROGRAM

VEGETATION MONITORING AT KALUAA AND WAIELI MANAGEMENT UNIT, 2015

INTRODUCTION

Vegetation monitoring was conducted at Kaluaa and Waieli Management Unit (MU) in 2015 in association with MIP/OIP requirements for long term monitoring of vegetation composition and change over time (OANRP 2008) (Figure 1). The primary objective of MU monitoring is to assess if the percent cover of non-native plant species is less than 50% across the MU, or is decreasing towards that threshold requirement. The secondary objective is to assess if native cover is greater than 50% across the MU, or is increasing towards that threshold recommendation. Kaluaa and Waieli MU vegetation monitoring occurs on a five-year interval, and took place once previously in 2010 (OANRP 2011). Previous monitoring indicated that goals were met only for the non-native understory cover. The MU consists of three subunits. The Subunit I fence was completed in 2001, Subunit II was completed in 2006, and Subunit III was completed in 2010.

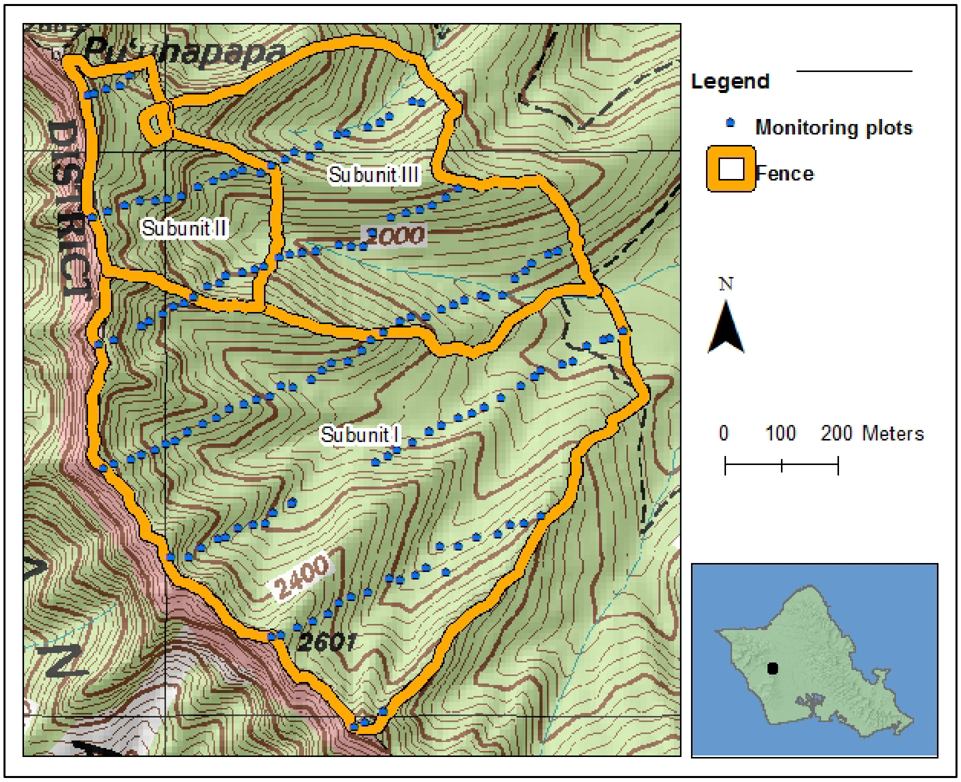

Figure 1. Kaluaa and Waieli MU vegetation monitoring plot locations.

METHODS

In August and September 2015, 148 plots were monitored along seven transects. Transects were spaced approximately 200 meters (m) apart, and plots measuring 5 x 10 m were generally located every

30 m along transects. These same plots were also monitored in 2010 (OANRP 2011). One additional plot was monitored in 2010, but was determined to be too dangerous for monitoring in 2015. Understory [occurring from 0 – 2 m above ground level (AGL), including low branches from canopy species] and canopy (occurring > 2 m AGL, including epiphytes) vegetation was recorded by percent cover for all non-native and native species present. Summary percent cover by vegetation type (shrub, fern, grass/sedge) in the understory, overall summary percent cover of non-native and native vegetation in the understory and canopy, and bare ground (non-vegetated < 25 cm AGL), were also documented. Percent cover categories were recorded in 10% intervals between 10 and 100%, and on finer intervals (0-1%, 1-5%, and 5-10%) between 0 and 10% cover. Understory recruitment (defined as seedlings or saplings < 2 m AGL) data for tree species was recorded in 2015, but not documented previously. Monitoring results were compared with data from 2010. Based on MIP recommendations, $\alpha = 0.05$ was used for significance determinations, and only cover changes ≥ 10% were recognized. Additional methodology information is detailed in Monitoring Protocol 1.2.1 (OANRP 2008). All analyses were performed in IBM SPSS Statistics Version 20. These included Wilcoxon signed-rank tests for cover data, paired t tests for species richness data, McNemar's test for frequency data, regression analyses for time spent weeding in association with cover change, and t tests for cover change in plots within vs. outside weed control areas.

RESULTS

Understory and canopy cover categories

Management objectives of having < 50% non-native understory and canopy and > 50% native understory and canopy cover were only met with respect to the non-native understory in 2015 (Table 1). Native understory and canopy percent cover were low (7.5% and 25% median values, respectively). Non-native understory cover was moderate, and non-native canopy cover was high (35% and 85% median values, respectively). There were several significant[1] changes in percent cover of vegetation from previous monitoring results (Figure 2). These included small decreases in cover for native shrubs, total native understory, and bare ground. Both native and non-native canopy (as well as total native and non-native canopy) had small significant increases. In some instances (native canopy and total canopy), significant change occurred in relative distributions, while median values remained unchanged. Only bare ground and non-native canopy met the 10% standard for recognized change in cover. However, caution should be applied in interpreting the results of change in bare ground, as the method for this measurement was not as clearly defined in 2010, and as such was less repeatable. There was also a marginally significant increase in non-native ferns. In 2015, higher native understory cover occurred primarily at mid- and high elevations. Locations of low to high percent cover of non-native understory and native canopy were patchily distributed across the MU. High percent cover of non-native canopy was nearly consistently distributed across the MU (Figure 3). Locations where beneficial and worsening cover changes occurred were patchily distributed (Figure 4).

[1]**Notes for readers less familiar with statistics:** Statistical significance is determined by p-values. P-values indicate to what extent the results support a hypothesis (the lower the number, the stronger the support for the hypothesis). In this study, the hypotheses would be that there are changes occurring in percent cover, frequency, and species richness. In this study, p-values less than 0.05 were significant. P-values only slightly greater than 0.05 were denoted as marginally significant, meaning that while not technically significant, they are worthy of note, e.g., perhaps a change is occurring, but at a gradual rate that may only become apparent in future monitoring, should that pattern continue. In some instances, there may be significant p-values despite no change in median values, if change occurred in the distribution of data, e.g., percent cover may range from 15 to 35 with a median of 25 one year, then the next year have a range of 15 to 95 but still have a median of only 25.

Table 1. Percent cover of native and non-native vegetation categories in the canopy and understory at Kaluaa and Waieli MU from 2010 to 2015. Median values are represented (n = 148). Statistically significant values are in boldface (Wilcoxon signed-rank test). Categories specifically addressed in management objectives are shaded. Arrows indicate increase (↑) or decrease (↓) in cover. *Meets 10% standard for recognized change in cover.

	2010	2015	p	Z	Management objective currently met?
Understory					
Native shrubs	7.5	2.5	**< 0.001**↓	-6.07	
Native ferns	2.5	2.5	0.476	-0.71	
Native grasses	0.0	0.0	0.875	-0.16	
Total native understory	15.0	7.5	**< 0.001**↓	-3.6	No, and may be getting worse
Non-native shrubs	25.0	15.0	0.535	-0.62	
Non-native ferns	2.5	2.5	0.06↑	-1.88	
Non-native grasses	0.0	0.0	0.073	-1.8	
Total non-native understory	35.0	35.0	0.753	-0.31	Yes
Bare ground	85.0	75.0	**< 0.001***↓	-3.68	
Canopy					
Native canopy	25.0	25.0	**0.019**↑	-2.35	No, but may be getting better
Non-native canopy	75.0	85.0	**0.001***↑	-3.33	No, and getting worse
Total canopy	95.0	95.0	**< 0.001**↑	-4.1	

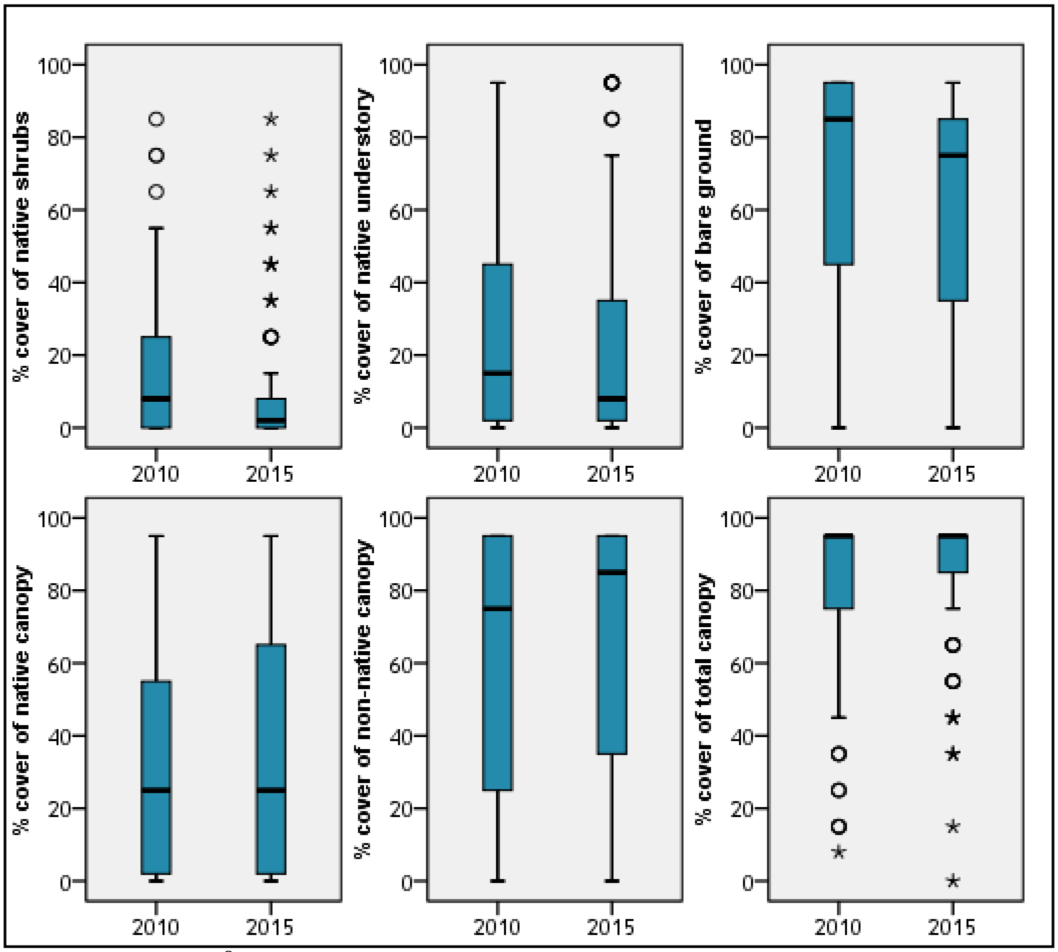

Figure 2. Boxplots[2] for vegetation categories with significant change in percent cover between years 2010 and 2015 in Kaluaa and Waieli MU.

[2]**Additional notes for readers less familiar with statistics**: Boxplots show the range of data values for a given variable, analogous to a squashed bell curve turned on its side. The shaded boxes depict 50% of the data values, and the horizontal line inside the shaded box represents the median value. In this report, very high or low values relative to the shaded box are indicated by circles (1.5 to 3 times the length of the shaded box) and asterisks (> 3 times the length of the shaded box), while the lines extending above and below the shaded box depict the range in values for all remaining data. Circles and asterisks that appear to be in boldface indicate multiple data points for the same values.

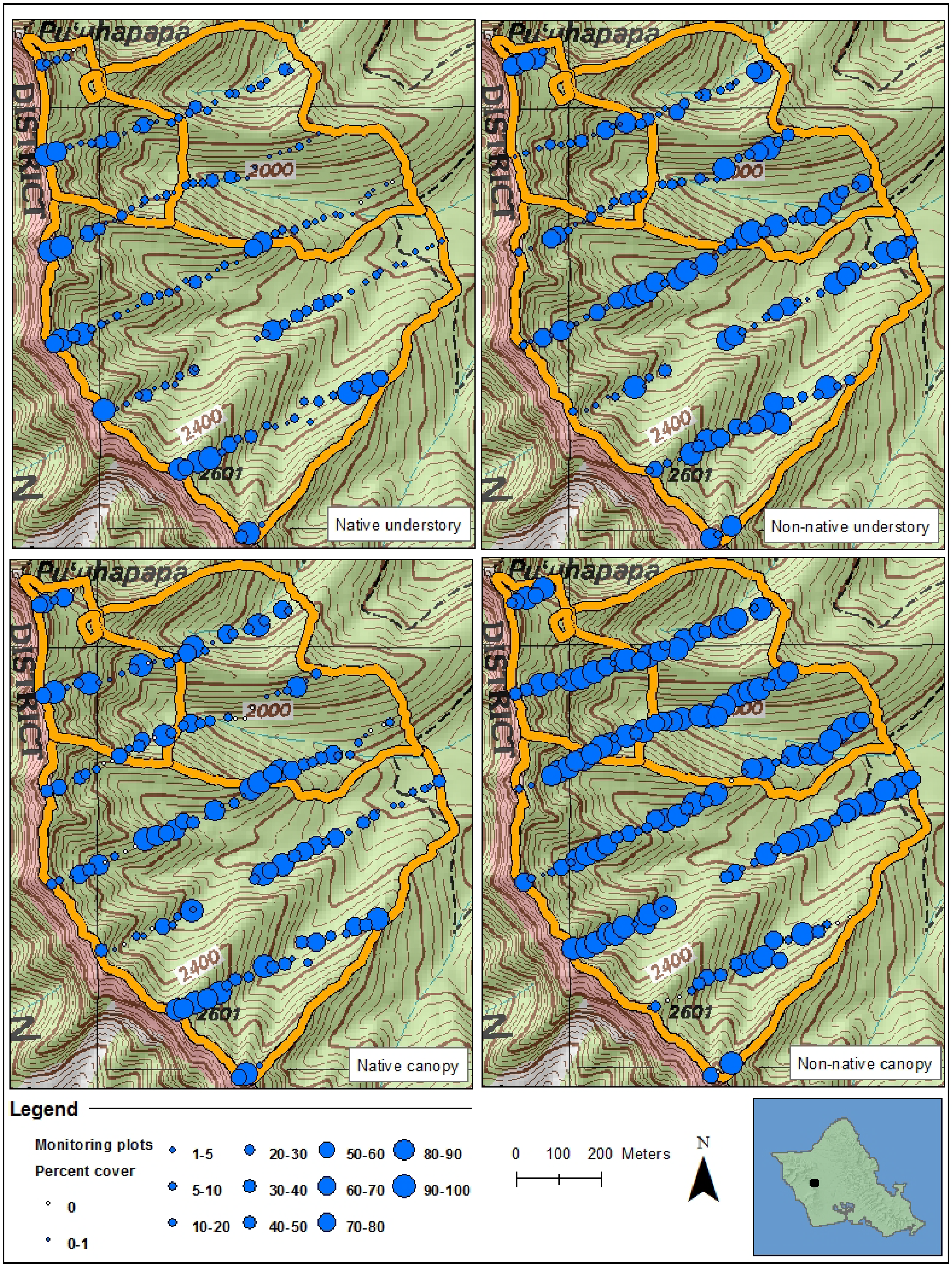

Figure 3. Locations of low to high percent cover of native and non-native understory and canopy vegetation among monitored plots at Kaluaa and Waieli MU in 2015. Larger circles denote higher percent cover, while smaller circles represent lower cover.

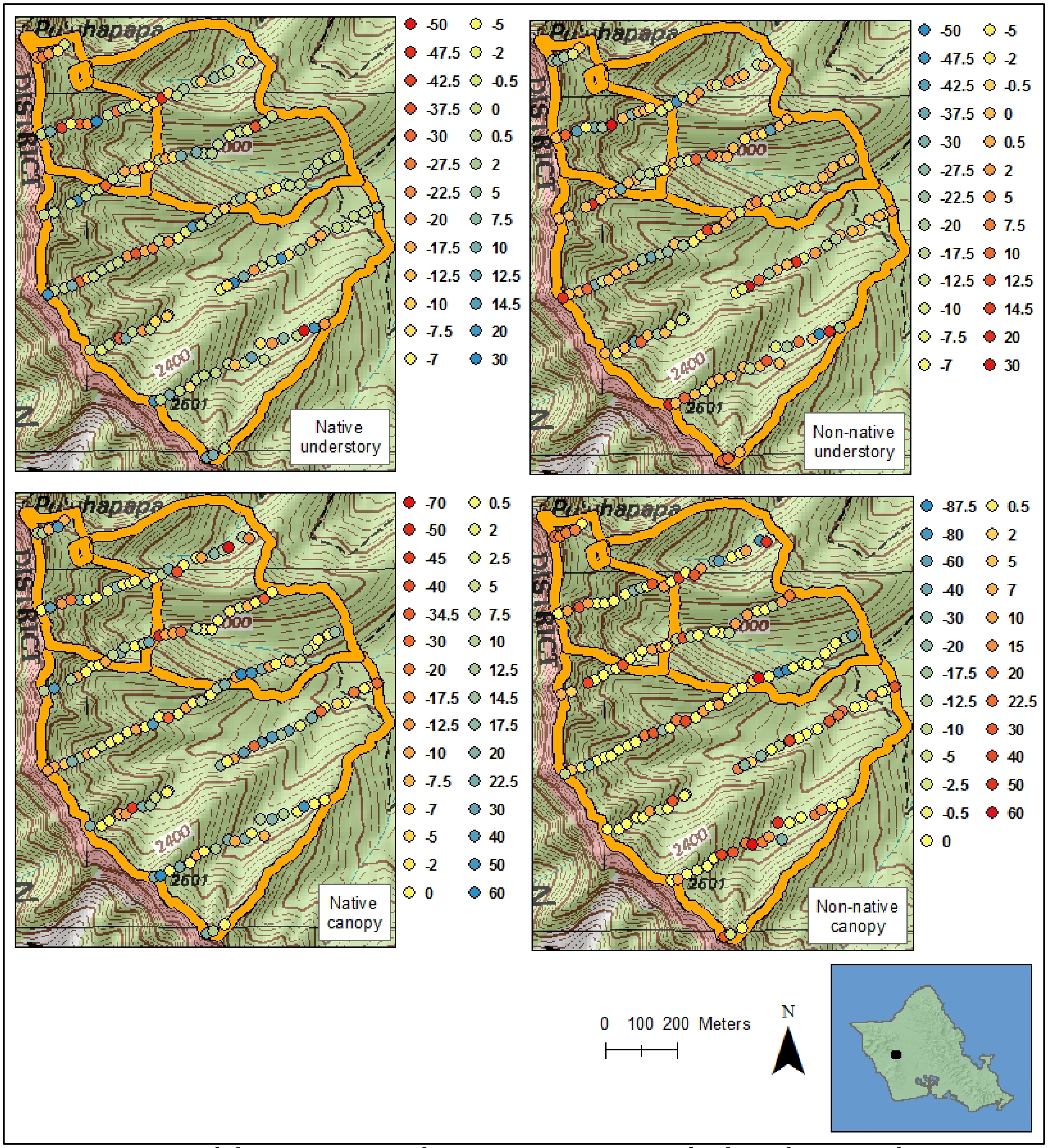

Figure 4. Locations of change in native and non-native percent cover for the understory and canopy vegetation in monitored plots in Kaluaa and Waieli MU between 2010 and 2015. Color gradients are inverted for native and non-native vegetation, such that blue indicates beneficial change, red depicts worsening conditions. Cover change of 0 indicates there was no change in percent cover.

Species richness

During monitoring in 2015, 165 species were recorded in the understory (61% native taxa), and 75 were identified in the canopy (73% native). Most species present in the canopy were also represented in the understory, with the exception of three native species (*Cyanea superba* subsp. *superba*, *Korthalsella degeneri*, and *Nestegis sandwicensis*). Locations of high and low species richness for the native and non-native understory and canopy were primarily patchily distributed across the MU (Figure 5). Species richness differed significantly between the years monitored, with a small decrease in in the non-native understory, and a small increase in the non-native canopy within plots (Table 2). No detectable change occurred in species richness among plots in the native understory or canopy. Despite the significant decrease in non-native understory richness among plots, the overall non-native understory (as well as canopy) diversity for the MU increased slightly. Overall native understory and canopy diversity for the MU decreased. Sixteen new species (62.5% non-native) were found in plots in 2015, while 20 species (30% non-native) were recorded in 2010 but not observed in 2015 (Table 3). The presence or absence of species may be due in part to human error such as misidentification (e.g., difficulties in distinguishing *Korthalsella* taxa), observer bias regarding plot boundaries or amount of time spent searching, or accidental non-recording. The occurrence within plots of short-lived, less common species is expected to vary over time. All of the species that were not present in 2015 were uncommon in previous years, with frequencies less than 0.02.

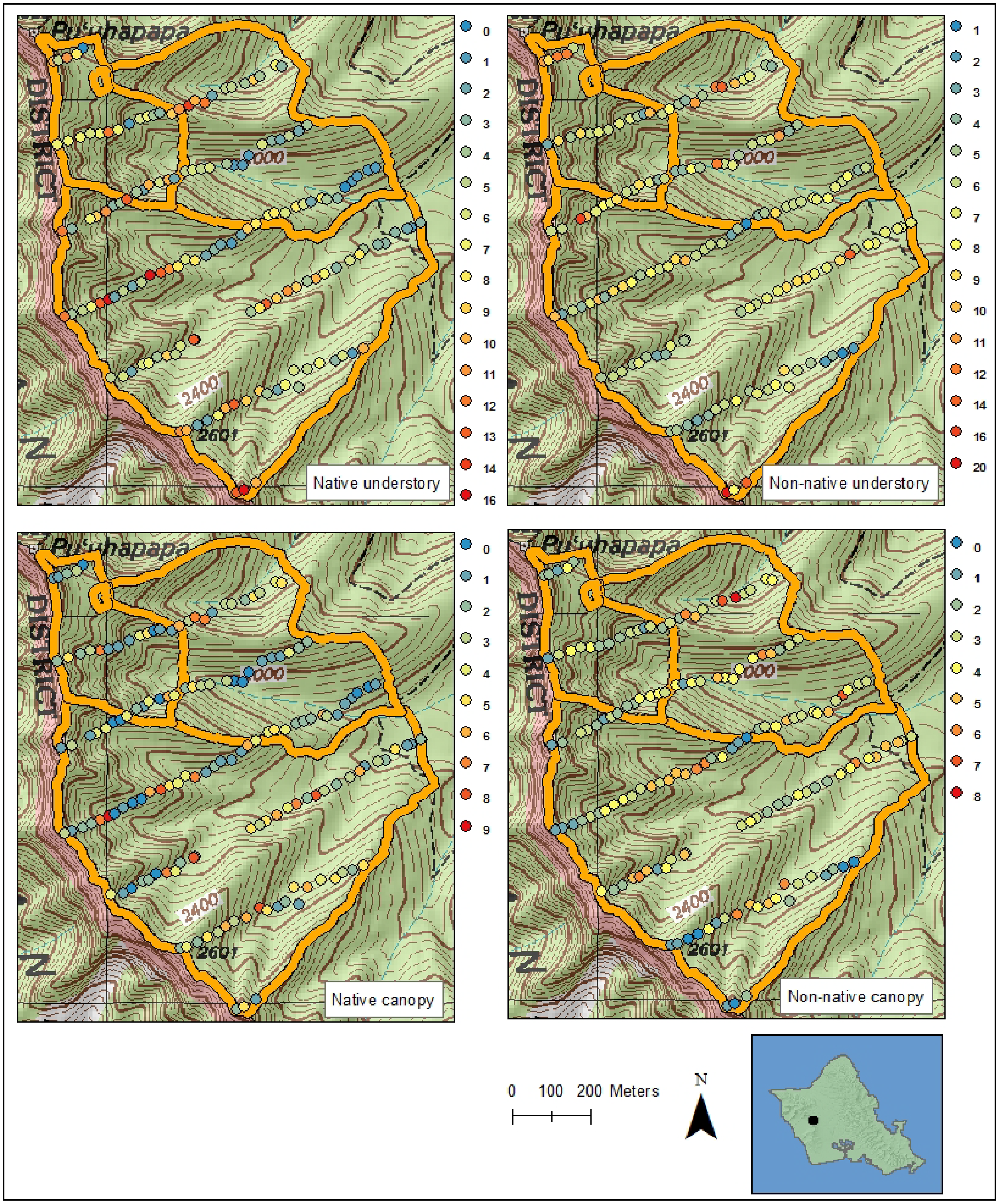

Figure 5. Locations of low to high species richness among plots in the native and non-native understory and canopy in Kaluaa and Waieli MU, 2015. Color gradients of blue to red indicate low to high values, respectively, of the number of species occurring in plots (i.e., blue indicates low diversity, while red indicates relatively higher diversity).

Table 2. Kaluaa and Waieli MU understory and canopy species richness. Mean species richness per plot during vegetation monitoring is shown by year, with the total number of species recorded among all plots in parenthesis (n = 148). P-values obtained from paired t tests. Statistically significant values are in boldface. Arrows indicate increase (↑) or decrease (↓) in richness.

	2010	2015	p	t
Native understory	6.43 (111)	6.17 (101)	0.109	-1.613
Non-native understory	7.39 (60)	6.82 (64)	**0.011**↓	-2.575
Native canopy	2.84 (57)	3.00 (55)	0.096	1.674
Non-native canopy	2.73 (18)	3.16 (20)	< **0.001**↑	4.231

Table 3. Newly recorded, and no longer present, species from 2015 Kaluaa and Waieli MU monitoring, in the understory and/or canopy. Native taxa are in boldface.

New species recorded in plots in 2015	Species found in plots in 2010 but not recorded in 2015
Adenophorus tenellus	***Alectryon macrococcus var. macrococcus***
Bidens alba	*Anagallis arvensis*
Castilleja arvensis	*Arundina gramminifolia*
Cyrtomium falcatum	***Broussaisia arguta***
Epidendrum x obrienianum	***Cyanea angustifolia***
Eucalyptus robusta	*Drymaria cordata var. pacifica*
Korthalsella cylindrica	***Dubautia laxa***
Korthalsella platycaula	***Ilex anomala***
Myrsine lanaiensis	***Korthalsella complanata***
Oxalis corymbosa	*Leucaena leucocephala*
Peperomia blanda	***Lobelia yuccoides***
Peperomia membranacea	***Lysimachia hillebrandii***
Polystachya concreta	*Melia azedarach*
Syzygium cumini	***Myrsine sandwicensis***
Syzygium jambos	***Neraudia melastomifolia***
Verbena litoralis	*Plantago lanceolata*
	Rumex albescens
	Sapindus oahuensis
	Solanum sandwicense
	Zanthoxylum kauaense

Species frequency

Non-native species that occurred most frequently in plots (present in more than half the plots) in the understory included *Clidemia hirta, Passiflora suberosa, Blechnum appendiculatum,* and *Schinus terebinthifolius,* while those most commonly occurring in the canopy were *S. terebinthifolius* and *P. suberosa* (Table 4). The most frequent native species (in at least a third of the plots) included *Alyxia stellata* and *Doodia kunthiana* in the understory, and *Acacia koa* in the canopy. *Alyxia stellata* is often the final native species remaining in *P. cattleianum* dominated forests (K. Kawelo, pers comm.). Of the 27 rare taxa occurring at Kaluaa and Waieli MU (OANRP 2011), 8 were identified during monitoring in 2015. Analysis of frequency change (McNemar's test) was limited to taxa with at least ten percent change between 2010 and 2015. These included two non-native species each in the understory and canopy, all of which had significant frequency changes (Table 5). Frequency declined for *Toona ciliata* and *Youngia japonica* by 10% each in the understory, and increased for *P. suberosa* (by 12%) and *Toona ciliata* (by 15%) in the canopy.

Table 4. Species frequency among plots (proportion of plots in which a given species occurs) during 2015 Kaluaa and Waieli MU monitoring (n= 148), in order of most to least frequent. Native species are in bold print. *Rare taxa. **Target weed taxa.

Taxon	Freq.	Taxon	Freq.	Taxon	Freq.	Taxon	Freq.
Understory							
Clidemia hirta	0.878	*Psidium guajava*	0.081	***Selaginella arbuscula***	0.027	***Asplenium excisum***	0.007
Passiflora suberosa	0.777	***Asplenium caudatum***	0.074	***Strongylodon ruber****	0.027	***Asplenium nidus***	0.007
Blechnum appendiculatum	0.574	***Diospyros hillebrandii***	0.074	*Urochloa maxima***	0.027	*Bidens alba*	0.007
Schinus terebinthifolius	0.547	*Physalis peruviana*	0.074	*Andropogon virginicus*	0.020	***Bobea elatior***	0.007
Psidium cattleianum	0.473	*Aleurites moluccana*	0.068	*Crassocephalum crepidoides*	0.020	*Castilleja arvensis*	0.007
Cyclosorus parasiticus	0.453	***Antidesma platyphyllum***	0.068	***Cyanea pinnatifida****	0.020	***Charpentiera tomentosa***	0.007
*Toona ciliata***	0.385	***Caesalpinia bonduc***	0.068	***Delissea waianaeensis****	0.020	*Cheilanthes viridis*	0.007
Alyxia stellata	0.358	***Myrsine lessertiana***	0.068	*Deparia petersenii*	0.020	***Chrysodracon forbesii****	0.007
Lantana camara	0.351	***Psychotria hathewayi***	0.068	***Dryopteris glabra***	0.020	***Clermontia persicifolia***	0.007
Doodia kunthiana	0.345	***Bidens torta***	0.061	***Elaeocarpus bifidus***	0.020	***Ctenitis latifrons***	0.007
Microlepia strigosa	0.297	***Nephrolepis cordifolia***	0.061	***Gahnia beecheyi***	0.020	***Cyrtomium caryotideum***	0.007
Planchonella sandwicensis	0.284	***Psydrax odorata***	0.061	***Huperzia phyllantha***	0.020	***Dryopteris fusco-atra***	0.007
Acacia koa	0.277	***Kadua affinis***	0.054	***Kadua cordata***	0.020	***Elaphoglossum alatum***	0.007
Phlebodium aureum	0.270	*Kalanchoe pinnata*	0.054	*Musa sp.*	0.020	*Emilia sonchifolia*	0.007
Rubus rosifolius	0.270	***Leptecophylla tameiameiae***	0.054	*Nephrolepis brownii*	0.020	*Epidendrum x obrienianum*	0.007
Cocculus orbiculatus	0.236	*Buddleja asiatica*	0.047	***Peperomia tetraphylla***	0.020	*Eucalyptus robusta*	0.007
Psychotria mariniana	0.196	***Cibotium chamissoi***	0.047	***Phyllanthus distichus***	0.020	***Gynochthodes trimera***	0.007
Metrosideros polymorpha	0.182	***Coprosma longifolia***	0.047	***Pteridium aquilinum***	0.020	***Korthalsella cylindrica***	0.007
Oplismenus hirtellus	0.182	***Kadua acuminata***	0.047	*Stachytarpheta australis*	0.020	*Kyllinga brevifolia*	0.007
Coprosma foliosa	0.176	***Labordia kaalae****	0.047	*Triumfetta semitriloba***	0.020	*Lophostemon confertus*	0.007
Asplenium macraei	0.162	***Sphenomeris chinensis***	0.047	***Vaccinium reticulatum***	0.020	***Machaerina angustifolia***	0.007
Melinis minutiflora	0.155	*Youngia japonica*	0.047	*Adiantum hispidulum*	0.014	*Mesosphaerum pectinatum*	0.007
Carex wahuensis	0.142	*Cordyline fruticosa*	0.041	***Cyperus hypochlorus***	0.014	***Myrsine lanaiensis***	0.007
Grevillea robusta	0.142	***Diplazium sandwichianum***	0.041	*Cyrtomium falcatum*	0.014	*Oxalis corymbosa*	0.007
Nephrolepis exaltata	0.142	***Dodonaea viscosa***	0.041	***Diospyros sandwicensis***	0.014	***Peperomia blanda***	0.007
Canavalia galeata	0.135	***Pisonia brunoniana***	0.041	***Doryopteris decipiens***	0.014	***Pittosporum glabrum***	0.007
Dianella sandwicensis	0.128	***Pisonia sandwicensis***	0.041	***Eragrostis grandis***	0.014	*Polystachya concreta*	0.007
Lepisorus thunbergianus	0.128	*Ipomoea cairica*	0.034	*Erechtites valerianifolia*	0.014	*Rivina humilis*	0.007
Euphorbia multiformis	0.122	*Passiflora edulis*	0.034	*Heliocarpus popayanensis***	0.014	***Sadleria cyatheoides***	0.007
Pipturis albidus	0.122	***Psilotum nudum***	0.034	***Korthalsella platycaula***	0.014	*Schefflera actinophylla***	0.007
Pisonia umbellifera	0.122	***Scaevola gaudichaudiana***	0.034	*Mallotus phillippenis***	0.014	***Schiedea kaalae****	0.007
Dicranopteris linearis	0.115	***Smilax melastomifolia***	0.034	***Melicope clusiifolia***	0.014	*Setaria palmifolia***	0.007
Freycinetia arborea	0.108	*Spathodea campanulata***	0.034	*Melinis repens*	0.014	*Setaria parviflora*	0.007
Charpentiera obovata	0.101	***Streblus pendulinus***	0.034	***Peperomia membranacea***	0.014	*Syzygium cumini*	0.007
Conyza bonariensis	0.101	*Adiantum radianum*	0.027	***Psilotum complanatum***	0.014	***Syzygium sandwicense***	0.007
Dryopteris sandwicensis	0.095	*Cyclosorus dentatus*	0.027	***Pteralyxia macrocarpa****	0.014	***Vandenboschia cyrtotheca***	0.007
Tectaria gaudichaudii	0.095	***Elaphoglossum paleaceum***	0.027	***Santalum freycinetianum***	0.014	*Verbena litoralis*	0.007
Paspalum conjugatum	0.088	*Erigeron karvinskianus***	0.027	*Syzygium jambos*	0.014	***Viola chamissoniana***	0.007
Ageratina riparia	0.081	***Melicope oahuensis***	0.027	***Urera glabra***	0.014	***Xylosma hawaiiense***	0.007
Carex meyenii	0.081	***Microlepia speluncae***	0.027	***Adenophorus tenellus***	0.007		
Claoxylon sandwicensis	0.081	***Panicum nephelophilum***	0.027	*Ageratum conyzoides*	0.007		
Oxalis corniculata	0.081	*Salvia occidentalis*	0.027	***Asplenium contiguum***	0.007		

Table 4, continued.

Taxon	Freq.	Taxon	Freq.	Taxon	Freq.	Taxon	Freq.
Canopy							
Schinus terebinthifolius	0.676	***Claoxylon sandwicensis***	0.061	***Antidesma platyphyllum***	0.027	***Nestegis sandwicensis***	0.014
Passiflora suberosa	0.554	***Freycinetia arborea***	0.061	***Labordia kaalae****	0.027	***Pteralyxia macrocarpa****	0.014
*Toona ciliata***	0.466	***Diospyros hillebrandii***	0.054	***Lepisorus thunbergianus***	0.027	***Santalum freycinetianum***	0.014
Psidium cattleianum	0.432	***Gynochthodes trimera***	0.054	***Pisonia brunoniana***	0.027	***Syzygium sandwicense***	0.014
Acacia koa	0.351	***Myrsine lessertiana***	0.054	***Smilax melastomifolia***	0.027	***Urera glabra***	0.014
Metrosideros polymorpha	0.297	*Phlebodium aureum*	0.054	*Cordyline fruticosa*	0.020	***Asplenium nidus***	0.007
Planchonella sandwicensis	0.291	***Streblus pendulinus***	0.054	***Kadua affinis***	0.020	***Bobea elatior***	0.007
Psychotria mariniana	0.230	***Cibotium chamissoi***	0.047	***Korthalsella degeneri****	0.020	***Chrysodracon forbesii***	0.007
Alyxia stellata	0.216	***Coprosma foliosa***	0.047	***Korthalsella platycaula***	0.020	***Clermontia persicifolia***	0.007
Aleurites moluccana	0.203	***Dicranopteris linearis***	0.047	*Physalis peruviana*	0.020	***Cyanea superba subsp. superba****	0.007
Grevillea robusta	0.203	*Lantana camara*	0.047	*Rubus rosifolius*	0.020	***Euphorbia multiformis***	0.007
Canavalia galeata	0.122	***Leptecophylla tameiameiae***	0.047	***Scaevola gaudichaudiana***	0.020	***Kadua acuminata***	0.007
Clidemia hirta	0.115	***Pisonia sandwicensis***	0.047	***Charpentiera obovata***	0.014	*Lophostemon confertus*	0.007
Passiflora edulis	0.108	***Psychotria hathewayi***	0.047	***Coprosma longifolia***	0.014	*Melinis minutiflora*	0.007
Psidium guajava	0.108	***Strongylodon ruber****	0.047	***Diospyros sandwicensis***	0.014	***Nephrolepis exaltata***	0.007
Pipturis albidus	0.101	***Caesalpinia bonduc***	0.034	***Elaeocarpus bifidus***	0.014	***Peperomia tetraphylla***	0.007
Pisonia umbellifera	0.101	***Cocculus orbiculatus***	0.034	***Korthalsella cylindrica***	0.014	***Pittosporum glabrum***	0.007
Psydrax odorata	0.088	***Dodonaea viscosa***	0.034	***Melicope oahuensis***	0.014	*Spathodea campanulata***	0.007
Buddleja asiatica	0.061	*Ipomoea cairica*	0.034	*Musa sp.*	0.014		

Table 5. Species frequency change at Kaluaa and Waieli MU between 2010 and 2015. Only taxa with at least 10% change in frequency were analyzed. Frequency values represent the proportion of plots in which species are present (n = 148). Native species are in boldface. P-values obtained from McNemar's test. Arrows indicate increase (↑) or decrease (↓) in frequency.

Species	Frequency 2010	Frequency 2015	% change	p
Understory				
Toona ciliata	0.486	0.385	-10	0.018[a]↓
Youngia japonica	0.149	0.047	-10	< 0.001[b]↓
Canopy				
Passiflora suberosa	0.432	0.554	12	0.002[a]↑
Toona ciliata	0.318	0.466	15	< 0.001[a]↑

[a]Asymptotic significance. [b]Exact significance.

Species cover

Species with frequencies > 0.20 (present in at least 30 plots) in 2010 and/or 2015 were subjected to analysis of cover change (Wilcoxon signed-rank test). Fine scale cover categories between 0 and 10% were lumped into a single value to minimize the influence of very small differences on the analysis. Significant increases in percent cover occurred for one non-native understory species (*B. appendiculatum*), two native canopy species (*A. koa* and *Metrosideros polymorpha*), and three non-native canopy species (*P. suberosa*, *P. cattleianum*, and *T. ciliata*) (Table 6 and Figure 6). Decreases in percent cover occurred for two species in the non-native understory (*S. terebinthifolius* and *T. ciliata*). The median change in percent cover was 0.0% for all species (as most taxa were absent from more than half of the plots during both years, most plots maintained 0% cover). Among those with significant change in cover, three non-native taxa (*S. terebinthifolius* and *T. ciliata* in the understory, and *P. suberosa* in the canopy) were influenced by small cover changes resulting from being absent in one year, and present in 0-10% cover in the other year. The change in overall non-native canopy percent cover was likely driven by changes in *P. cattleianum* and *T. ciliata* cover, along with cumulative changes among multiple additional taxa.

Table 6. Percent cover change of native and non-native species in the canopy and understory at Kaluaa and Waieli from 2010 to 2015. Only species with frequencies greater than 0.20 (present in at least 30 plots) in 2010 and/or 2015 were analyzed. Native taxa and statistically significant values are in boldface (Wilcoxon signed-rank test, n = 148). Arrows indicate increase (↑) or decrease (↓) in cover.

Species	Median cover change	p	Z
Understory			
Acacia koa	0.0	0.439	-0.775
Alyxia stellata	0.0	0.131	-1.512
Blechnum appendiculatum	0.0	**0.001**↑	-3.437
Clidemia hirta	0.0	0.865	-0.170
Cocculus orbiculatus	0.0	0.099	-1.650
Cyclosorus parasiticus	0.0	0.346	-0.943
Doodia kunthiana	0.0	0.552	-0.595
Lantana camara	0.0	0.078	-1.764
Metrosideros polymorpha	0.0	0.876	-0.156
Microlepia strigosa	0.0	0.244	-1.165
Passiflora suberosa	0.0	0.475	-0.714
Phlebodium aureum	0.0	1.000	0.000
Planchonella sandwicensis	0.0	0.315	-1.006
Psidium cattleianum	0.0	0.247	-1.158
Psychotria mariniana	0.0	0.073	-1.795
Rubus rosifolius	0.0	0.499	-0.675
Schinus terebinthifolius	0.0	**0.008**↓	-2.658
Toona ciliata	0.0	**0.005**↓	-2.818
Canopy			
Acacia koa	0.0	**0.036**↑	-2.102
Aleurites moluccana	0.0	0.756	-0.311
Alyxia stellata	0.0	0.251	-1.147
Grevillea robusta	0.0	0.966	-0.043
Metrosideros polymorpha	0.0	**0.003**↑	-3.001
Passiflora suberosa	0.0	**0.025**↑	-2.239
Planchonella sandwicensis	0.0	0.602	-0.521
Psidium cattleianum	0.0	**0.000**↑	-3.751
Psychotria mariniana	0.0	0.330	-0.974
Schinus terebinthifolius	0.0	0.067↑	-1.834
Toona ciliata	0.0	**0.001**↑	-3.311

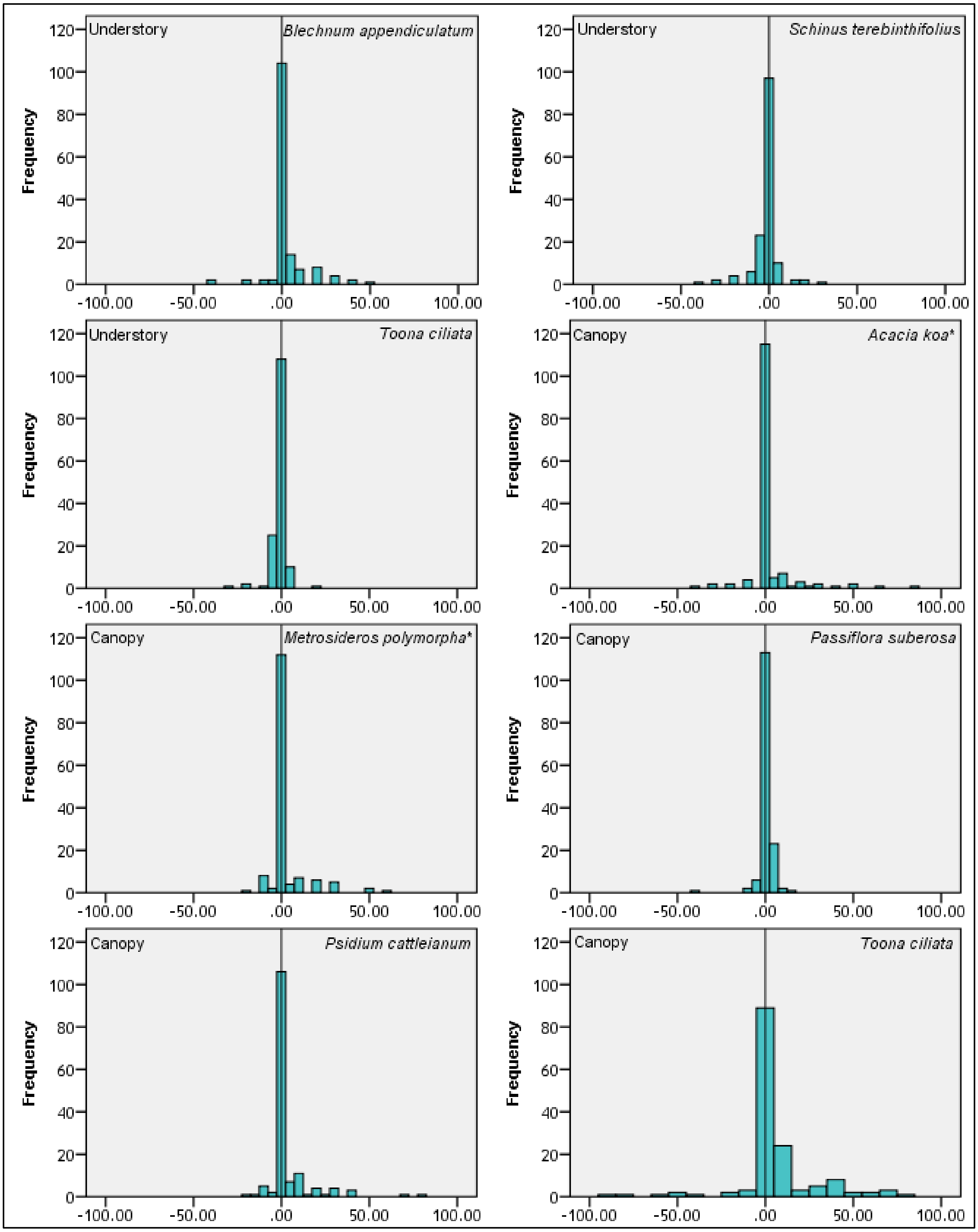

Figure 6. Histograms of percent cover change between 2010 and 2015 at Kaluaa and Waieli, for species with significant changes in cover in the understory and canopy. Solid lines reference 0% cover change (no change in cover within plots). Values > 0 represent increased cover in plots, while those < 0 represent decreased cover. *Native taxa.

Canopy replacement

Most canopy tree species were found recruiting in the understory (Table 7). *Acacia koa*, was the most commonly recruiting native tree species, while non-native recruiting tree species were primarily *P. cattleianum, T. ciliata,* and *S. terebinthifolius*. Native species with no recruitment in the understory were also infrequent in the canopy. It should be noted that the age of saplings may vary greatly, from less than one year to decades, in accordance with differing species and individual growth rates, complicating interpretations of presence/absence and change over time with respect to concerns over long term canopy replacement.

Table 7. Summary of canopy tree species recruitment in the understory during 2015 Kaluaa and Waieli MU monitoring, in order of most to least frequent. Frequency represents the occurrence of tree species with a maximum height < 2 meters (seedlings to small trees) among plots (n = 148). Native species are in boldface. *Rare taxa. **Target weed taxa.

Species	Freq.	Species	Freq.	Species	Freq.
Psidium cattleianum	0.331	***Pisonia sandwicensis***	0.027	*Schefflera actinophylla***	0.007
*Toona ciliata***	0.297	***Psydrax odorata***	0.027	*Syzygium cumini*	0.007
Acacia koa	0.257	***Diospyros hillebrandii***	0.020	***Xylosma hawaiiense***	0.007
Schinus terebinthifolius	0.243	***Labordia kaalae****	0.020	***Bobea elatior***	0.000
Planchonella sandwicensis	0.142	***Psychotria hathewayi***	0.020	***Charpentiera tomentosa***	0.000
Grevillea robusta	0.115	***Dodonaea viscosa***	0.014	***Chrysodracon forbesii****	0.000
Pisonia umbellifera	0.095	***Elaeocarpus bifidus***	0.014	***Cyanea superba* subsp. *superba****	0.000
Metrosideros polymorpha	0.081	***Myrsine lessertiana***	0.014	***Gynochthodes trimera***	0.000
Psychotria mariniana	0.081	*Syzygium jambos*	0.014	*Lophostemon confertus*	0.000
Charpentiera obovata	0.074	***Clermontia persicifolia***	0.007	***Melicope clusiifolia***	0.000
Pipturis albidus	0.074	***Diospyros sandwicensis***	0.007	***Myrsine lanaiensis***	0.000
Aleurites moluccana	0.061	*Eucalyptus robusta*	0.007	***Pittosporum glabrum***	0.000
Claoxylon sandwicensis	0.061	***Freycinetia arborea***	0.007	***Pteralyxia macrocarpa****	0.000
Psidium guajava	0.041	*Heliocarpus popayanensis***	0.007	***Santalum freycinetianum***	0.000
Antidesma platyphyllum	0.034	*Mallotus phillippenis***	0.007	***Syzygium sandwicense***	0.000
Spathodea campanulata	0.034	***Melicope oahuensis***	0.007	***Urera glabra***	0.000
Pisonia brunoniana	0.027				

Weed control

Weed control efforts at Kaluaa and Waieli between the 2010 and 2015 monitoring intervals included approximately 2,366 person hours. The total amount of effort varied among the nine weed control areas (WCA) that encompass the MU, ranging from 8 to 565.25 hours per WCA. Time spent weeding per WCA was weakly negatively correlated with change in native understory cover among the plots in areas where incision point application (IPA) canopy weeding of *T. ciliata* and *G. robusta* occurred (Pearson's correlation: $p = 0.019$, $r^2 = 0.119$, $n = 46$). I.e., native understory declined as time spent weeding per WCA increased, but only in plots that fell within IPA controlled areas; however time spent weeding explained very little of the variance in cover change. Aside from this, changes in native and non-native cover did not correlate with the amount of time spent weeding per WCA.

Between the 2010 and 2015 monitoring intervals, 36.7% of the MU was weeded. Much of the area weeded is attributable to IPA control (IPA control occurred across 26% of the MU, all other forms of weed control encompassed 15% of the MU). Weed control efforts crossed through 49% of the plots between the 2010 and 2015 monitoring intervals (31% fell within IPA control areas, 24% were within areas with all other forms of weeding) (Figure 7). Change in native and non-native cover did not differ among plots weeded vs. not weeded for all forms of weeding combined. Non-native canopy cover increased significantly (from a median of 55 to 70% cover) in plots outside IPA control areas (Wilcoxon: $p \leq 0.001$, $Z = 3.990$), but not within IPA areas (median of 95% cover both years) ($p = 0.818$, $Z = 0.231$) (Figure 8). There was no difference in change in native understory and canopy or non-native understory for plots within vs. outside IPA control areas. Upon further examination of *T. ciliata* and *G. robusta* canopy cover change in association with IPA efforts, the increase in *T. ciliata* cover (noted above) is attributable only to areas without IPA efforts (Wilcoxon: $p \leq 0.001$, $Z = 4.731$). Reduced cover of these taxa did not occur in plots in the IPA areas. Reductions in non-native understory or canopy did not correlate with increases in native or non-native understory or canopy vegetation among the monitored plots.

A third of the 27 target weed species (taxa of special concern for weed management, including incipient species) for Kaluaa and Waieli MU (OANRP 2011) were identified during monitoring, and at least one target taxa was present in 57% of the monitored plots in either the understory or canopy. These included one widespread target taxa (*T. ciliata*), and eight less common target species (*Erigeron karvinskianus*, *Heliocarpus popayanenesis*, *Mallotus philippensis*, *Schefflera actinophylla*, *Setaria palmifolia*, *Spathodea campanulata*, *Triumfetta semitriloba* and *Urochloa maxima*) (Figure 9). Of these, only *T. ciliata* had a high frequency, occurring in 52% of the plots. No incipient non-native taxa were identified in any plots.

Caution should be applied in interpreting the results of vegetation monitoring in association with weed control due to error associated with GIS data for both vegetation plots and weeded areas. Accuracy for vegetation plot locations was often poor, at times requiring hand plotting. Weeded areas were often hand plotted, with estimations of size and location that may be inexact to varying degrees.

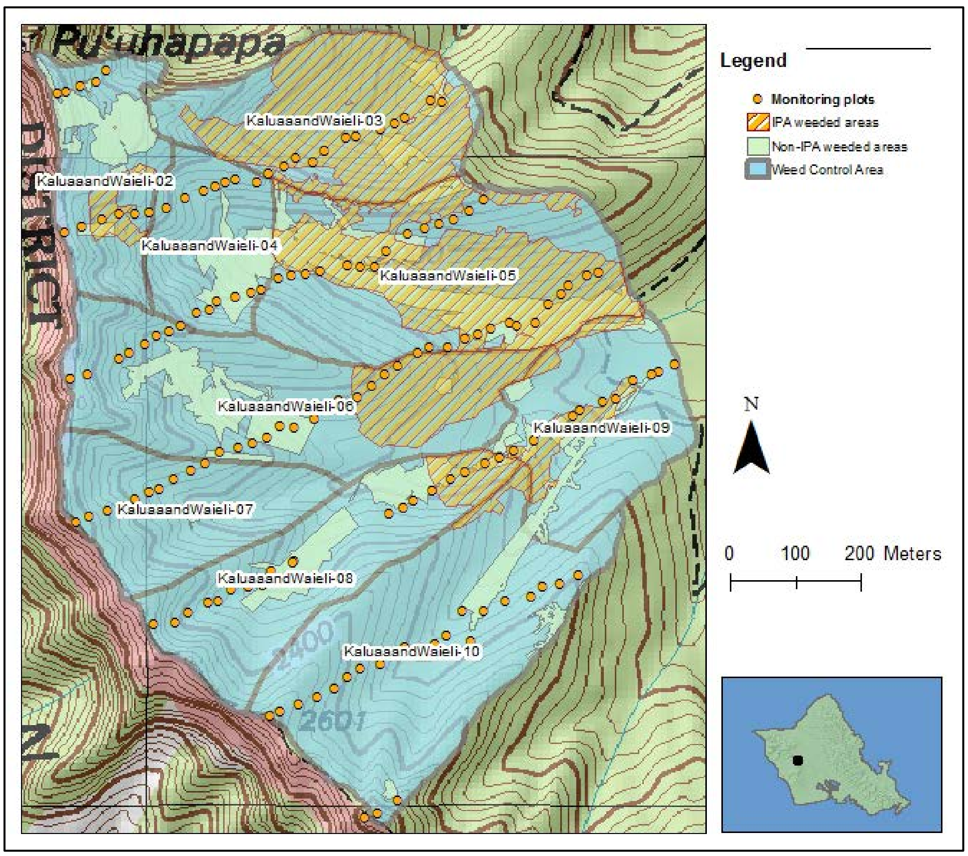

Figure 7. Locations of vegetation monitoring plots at Kaluaa and Waieli MU in relation to weed control areas (WCA) and areas weeded (showing locations with or without IPA control) between the 2010 and 2015 monitoring intervals.

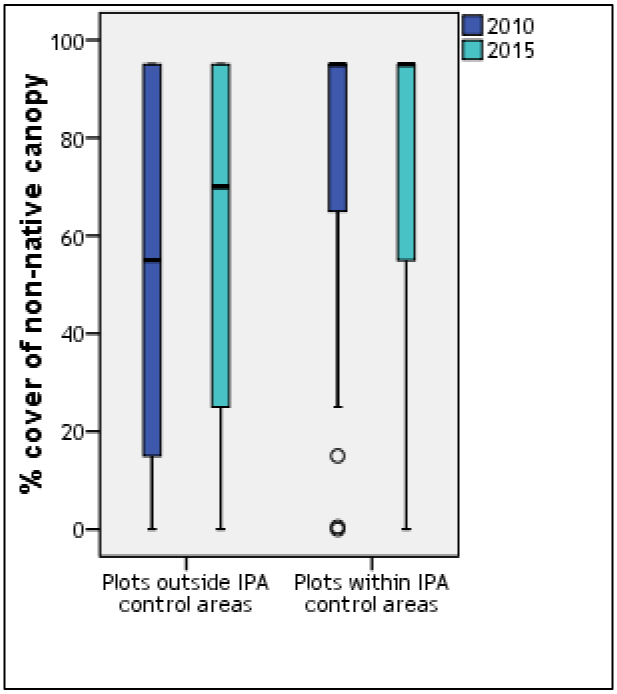

Figure 8. Non-native canopy cover in plots within vs. outside IPA weed control areas in 2010 and 2015.

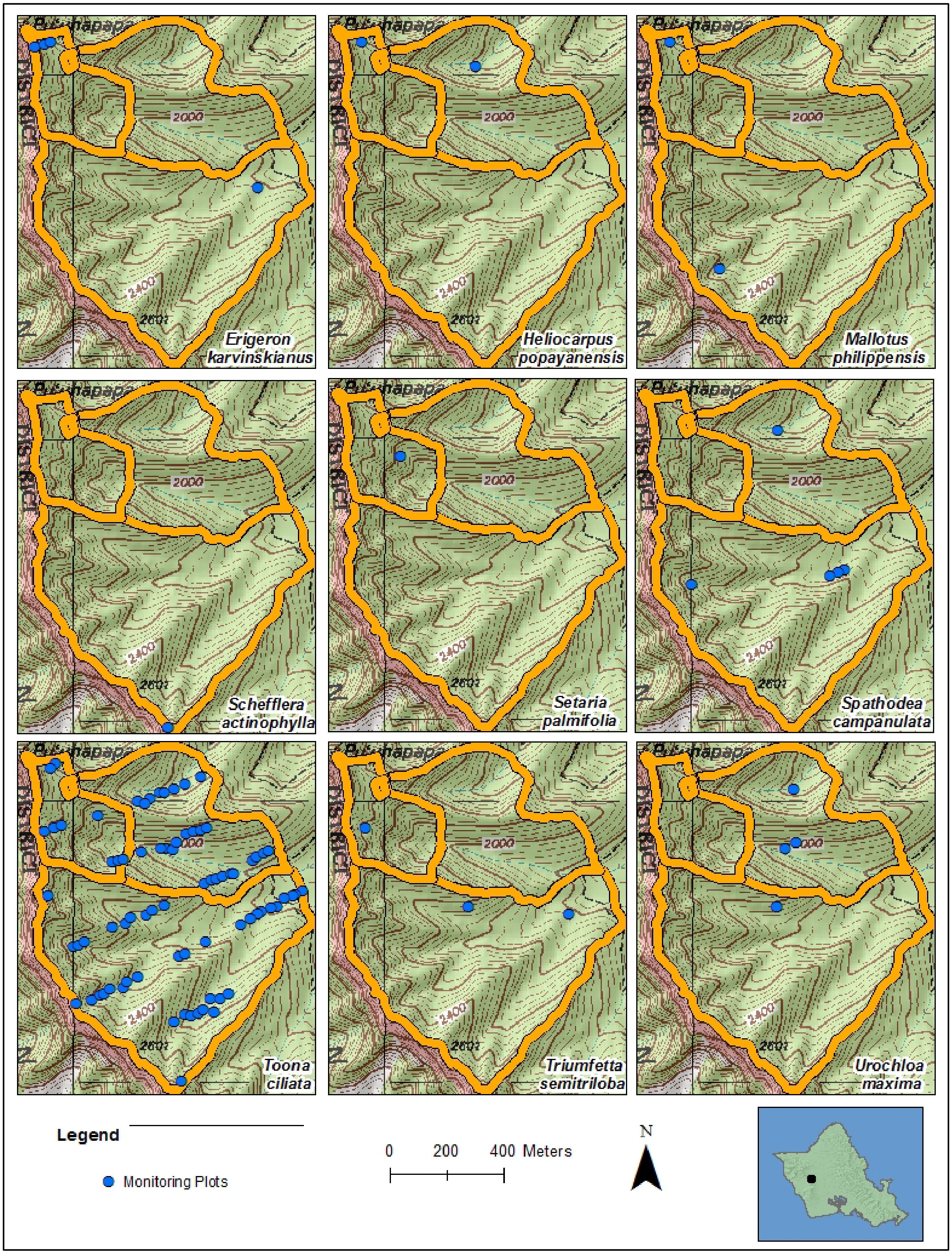

Figure 9. Locations of target taxa in the understory and/or canopy among plots in Kaluaa and Waieli MU in 2015.

SUMMARY AND DISCUSSION

Management objectives were not met for percent cover of native understory, native canopy, and non-native canopy vegetation for Kaluaa and Waieli MU. Objectives were only met for non-native understory percent cover. There were a number of noteworthy significant differences in the 2015 data as compared with five years ago, including:

- Increase in non-native canopy cover
- Decrease in non-native understory richness
- Increase in non-native canopy richness
- Decrease in frequency for non-native understory species:
    - *T. ciliata*
    - *Y. japonica*
- Increase in frequency for non-native canopy species:
    - *P. suberosa*
    - *T. ciliata*
- An increase in percent cover for non-native species:
    - *B. appendiculatum* (understory)
    - *P. suberosa* (canopy)
    - *P. cattleianum* (canopy)
    - *T. ciliata* (canopy)
- An increase in percent cover for native species:
    - *A. koa* (canopy)
    - *M. polymorpha* (canopy)
- A decrease in percent cover for non-native understory species:
    - *S. terebinthifolius* (understory)
    - *T. ciliata* (understory)
- Time spent weeding per WCA was negatively correlated with change in native understory cover among the plots within IPA control areas
- Increase in non-native canopy cover in plots without IPA control
- Increase in *Toona ciliata* (canopy) in plots without IPA control

The beneficial changes that occurred were generally small, while the worsening changes were larger, particularly in the canopy, irrespective of weeding efforts. Given the high level of non-native canopy cover in the MU, management goals of < 50% cover may be unrealistic across the MU. Refinement of management goals to apply specifically to prioritized areas (those with greater potential for restoration) within the MU may result in goals that are more likely to be successfully accomplished.

Toona ciliata frequency and cover decline in the understory paired with an increase in the canopy may be explained in part by vertical growth of individuals that were in the understory in 2010, but reached the canopy by 2015. Plots where *T. ciliata* was absent in the understory in 2015 but present in 2010 were anecdotally observed to have *T. ciliata* individuals in the lowermost portions of the canopy in 2015.

Changes in native and non-native cover resulting from IPA weed control efforts for *T. ciliata* and *G. robusta* are challenging to interpret. While time spent weeding per WCA was weakly negatively correlated with change in native understory cover among the plots within IPA control areas, there was no difference in cover change in plots within vs. outside IPA areas. Time spent weeding may be a poor indicator of effort with respect to IPA control, as considerably more area may be covered in a shorter time as compared with other types of weeding efforts, and could skew the results. The significant increase in non-native cover (including *T. ciliata*), in plots outside, but not inside, IPA controlled areas suggest IPA efforts may be preventing increases in non-native canopy cover within the areas treated. However, IPA treatment occurred in the lower elevations of the MU, where non-native cover was already uniformly high, as opposed to the higher elevation areas where non-native cover was lower. IPA control targeted only the largest mature individuals of two species in attempts to minimize primary seed sources, such that other non-native species and smaller individuals of the targeted taxa remained in the lower reached of the canopy, potentially masking impacts of canopy reduction via IPA. As IPA efforts expand into higher elevations, perhaps resulting canopy reduction will be more apparent.

RECOMMENDATIONS

Based on the results of vegetation monitoring, a number of recommendations were made with the goal of making progress towards meeting management objectives:

- more aggressive weed control paired with restoration efforts in prioritized areas
- target uncommon weeds when seen (particularly target taxa)
- expand IPA efforts into new areas, including higher elevations with more native cover, and continue IPA efforts within areas already treated, as *T. ciliata* and *G. robusta* grow to the targeted size/stage, as necessary
- monitoring of understory change in direct association with IPA treatments (via a separate monitoring regime) should be done to better understand it's impact on native and non-native understory cover
- there should be critical consideration and discussion of why change in native and non-native cover did not differ among weeded vs. not weeded plots in general, perhaps paired with smaller-scale monitoring of controlled weeding trials

REFERENCES

Oahu Army Natural Resource Program. 2008. Appendix 2.0 MIP/OIP Belt Plot Sampling Monitoring Protocol *in* 2008 Status Report for the Makua Implementation Plan.

Oahu Army Natural Resource Program. 2011. Chapter 1.2.1 Kaluaa and Waieli Ecosystem Restoration Management Unit Plan *in* 2011 Status Report for the Makua and Oahu Implementation Plans.